Self-assembly of hydrogen-bonded supramolecular strands from complementary melamine and barbiturate components with chiral selection

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Mixtures of the triamino triazines **1**–**6** with the complementary barbiturate **7** result in molecular recognition directed self-assembly in solution and in the solid state. The cocrystallization of enantiomerically pure **1** or **2** with **7** leads to the formation of supramolecular strands, which have been characterized by crystal structure determination. When a racemic mixture of **1** and **2** is used, chiral selection occurs within strands; two homochiral strands crystallize in the unit cell, each containing a different triazine enantiomer.

Self-assembly takes place in biological systems with a high level of control and efficiency based on the information stored within the individual components of the assembly (*e.g.* hydrogen bond patterns, electrostatic and steric features). An important goal in supramolecular chemistry is to understand how such information can be used in synthetic systems to spontaneously generate well-defined supramolecular architectures through molecular recognition directed self-assembly of suitably programmed molecular components.[1] This also represents an important step towards the construction of new materials endowed with a variety of properties.

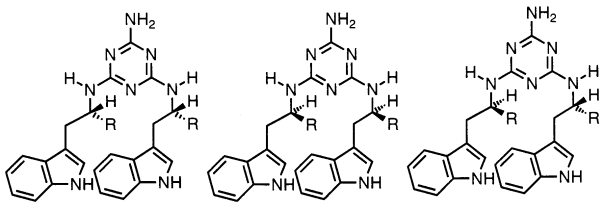
Recently, the self-assembly of triamino-pyrimidines (TAP) or -triazines (TAT) with complementary barbituarate components has been the focus of active investigation. Three motifs have been observed in the crystalline state for these compounds, linear ribbons or tapes,[2] crinkled tapes,[3] and supramoleular macrocycles or rosettes.[4] These studies have begun to uncover how the structural features of substituents, in particular on the TAT unit, induce the formation of a particular supramolecular structure. In continued efforts to understand how chirality can be used to direct self-assembly[5] we wish to report our results on a TAT–barbiturate assembly where the TAT unit bears chiral appendages.

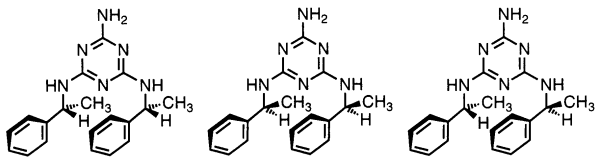
Results and Discussion

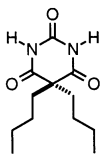
Preparation of the components and assemblies

We chose the amino acid tryptophan (Trp) and α-methylbenzylamine (α-MBA) as the chiral groups for our studies. Trp was selected because the indole moiety has a strong UV absorbance, is fluorescent and relatively lipophilic. It was used as its methyl ester Trp(OMe) to enhance solubility in organic solvents. All three stereoisomers of the bis(methyl tryptophanyl)amino triazines, (*S*,*S*) (**1**), (*R*,*R*) (**2**) and *meso* or (*R*,*S*) (**3**), as well as the bis(1-phenylethyl)amino triazines (*R*,*R*) (**4**), (*S*,*S*) (**5**) and (*R*,*S*) (**6**), were prepared. **1** and **2** were synthesized in *ca.* 80% yield by the addition of 2 equiv. of either D- or L-Trp(OMe) to 2-amino-4,6-dichloro-1,3,5-triazine[6] in a minimum amount of 1,4-dioxane and heating at 105 °C for 2 h. Extended reaction times led to large amounts of side-products. The *meso* isomer **3** was prepared in an analogous manner by sequential addition of D- then L-Trp(OMe) with isolation of the monosubstituted intermediate. The enantiomers **4** and **5** were prepared by adding an excess of optically pure α-MBA to 2-amino-4,6-dichloro-1,3,5-triazine in refluxing dioxane. The *meso* isomer **6** was obtained by preparation and isolation of the monosubstituted triazine followed by reaction with an excess of the enantiomeric amine. The triazines were all purified by flash chromatography. 5,5-Di(n-butyl)barbituric acid (DBB, **7**) was used as the complementary assembler and was prepared by condensation of urea with diethyl di(n-butyl)malonate.[7]

The crystals or powders obtained from 1 : 1 mixtures of DBB and the triazines† generally had higher melting points than those of the individual components: **1**, **2** mp: 110–117 °C; **3**: 142–146 °C; **7**: 157–158 °C; **1**·**7**, **2**·**7**: 198.8–200.6 °C; **3**·**7**: 168–171 °C. A racemic mixture containing the two enantiomeric TATs exhibited similar behavior (**1**·**2**·**7**$_2$







† Solids for melting points were obtained from stoichiometric mixtures of the desired triazines with **7** dissolved in hot ethyl acetate–hexane and cooled to room temperature. The overall 1 : 1 DBB:TAT composition was confirmed by ^{1}H NMR.

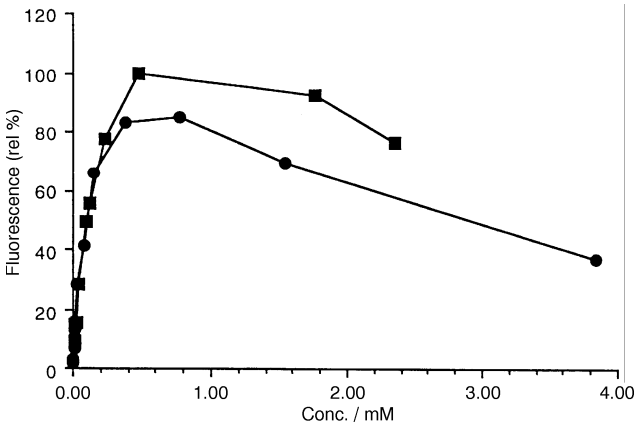


Fig. 1 Fluorescence spectra of the free triazine derivative **1**(*S*,*S*) (■) and of its 1 : 1 assembly **1** · **7** with the barbiturate **7** (●)

mp: 176–178 °C). However, a mixture containing all three TAT components in a ratio expected from a statistical synthesis of the triazines from 2-amino-4,6-dichloro-1,3,5-triazine and D,L-Trp(OMe) showed a well-defined melting point above that of the homochiral triazines **1** and **2**, but below the mp of either the *meso* isomer or the barbiturate (**1** · **2** · $\mathbf{3}_2$ · $\mathbf{7}_4$, mp: 128–130 °C). This is the first time that we have observed a TAT · bartiturate association with a melting point lower than that of any of the individual components. In the case of the α-MBA-bearing TATs (**4**–**6**), the mixtures all exhibited higher melting points than the components (**4**, **5** mp: 75.4–77.2 °C; **6**: 142–144 °C). Two-component mixtures (**4** · **7**, **5** · **7** mp: 220.5–222.0 °C; **6** · **7**: 219.0–219.6 °C) had higher melting points by about 20 °C than did the three- (**4** · **5** · $\mathbf{7}_2$ mp: 201.4–202.7 °C) or four-component mixtures (**4** · **5** · $\mathbf{6}_2$ · $\mathbf{7}_4$ mp: 201.8–203.5 °C). Also, the melting point of the 1 : 1 **6** · **7** species was nearly identical to that of the **4** · **7** or **5** · **7** complexes, even though the individual TAT components differed in melting points by nearly 70 °C.

Assembly in solution

The 200 MHz ^{1}H NMR spectrum of the triazines **1**–**3** were poorly resolved at 298 K, with all signals being broadened or doubled. This arises from slow rotation about the substituted amino nitrogen—triazine ring bond. The ^{13}C spectra were equally complex, giving rise to almost double the number of expected peaks. Addition of complement **7** to the triazines resulted in a downfield shift of both the barbiturate and TAT NH proton signals, indicative of hydrogen bonding. Distinct sharpening of peaks was also noted, with all signals resulting from the amino acid becoming well-resolved. This can be attributed to conversion to a unique conformation present in the assembly (*i.e.*, both amino acid substituents in the *syn* orientation). In the spectra of unassembled **1**–**3**, peaks representing the *syn* orientation of amino acids accounted for approximately 15% of the possible conformations.

An attempt to examine the effects of self-assembly on the optical rotation was hampered by the small specific rotation of **1** and **4** and the modest solubility of the assemblies (*ca.* 10 mM saturation). Over the concentration range examined, no effect of assembly on optical rotation was observed.

Fluorescence measurements were carried out on the Trp *S*,*S*-isomer **1** and on the 1 : 1 assembly **1** · **7** (Fig. 1). The presence of the barbiturate does not greatly affect the fluorescence of the system until assembly begins. The results suggest that self-association occurs in the absence of **7** at mM concentrations. However, in the presence of the assembler an additional 10–15% quenching occurs, suggesting that more indole moieties, responsible for the fluorescence, are held together. The measurements support a polymeric structure for the supramolecular assembly. As the concentration of the assembly increases the fluorescence reaches a maximum and then begins to fall off. If the compound were the closed rosette the fluorescence should not drop off, but remain constant to the limit of solubility. Thus the solution structure is likely a linear or crinkled tape.

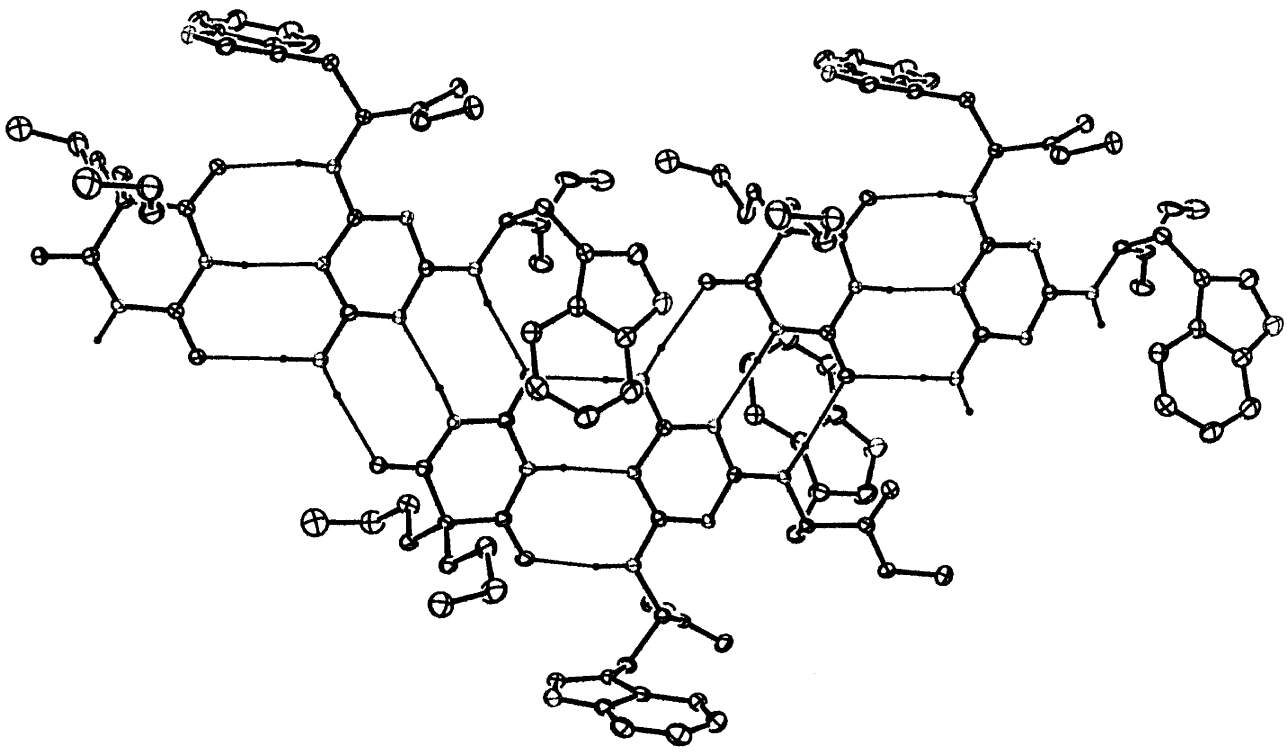


Fig. 2 ORTEP representation of the solid state structure of the homochiral assembly **1** · **7**. All hydrogen atoms not involved in hydrogen bonding are omitted for clarity. Ellipsoïds are scaled to enclose 30% of the electronic density. Hydrogen atoms have arbitrary radii

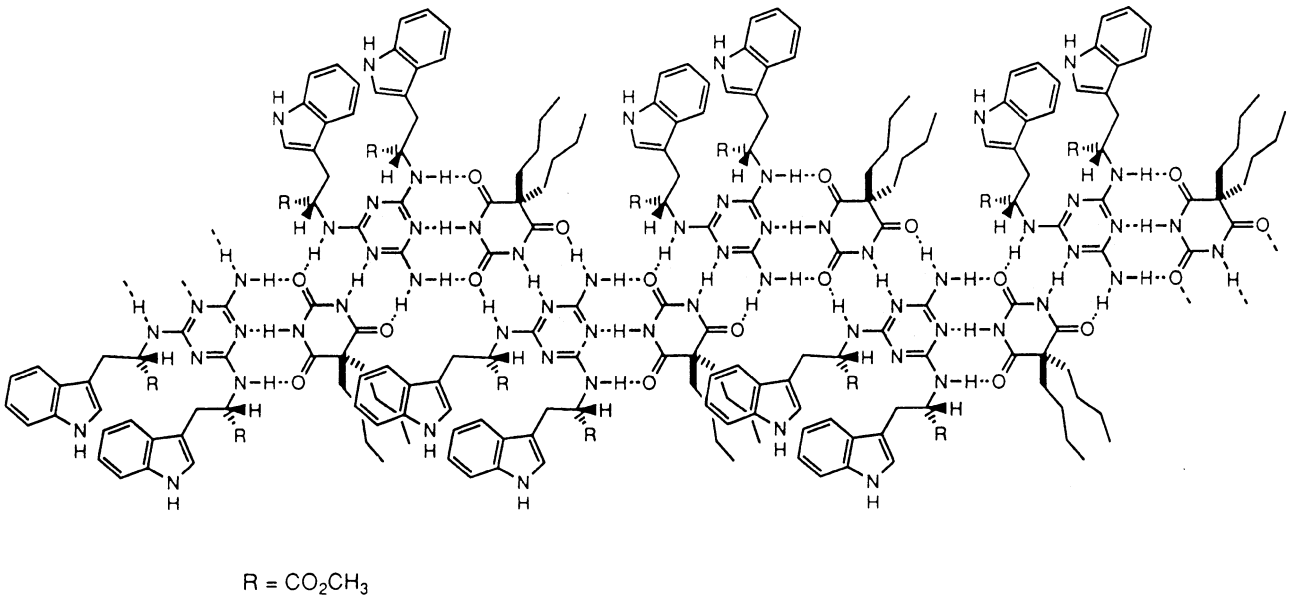


Fig. 3 Representation of the homochiral 'crinkled' tape formed by the **1** · **7** assembly

Structure of the solid state assemblies

Cocrystals suitable for X-ray analysis were obtained for the enantiomerically pure and the racemic triazine · barbiturate assemblies **1** · **7** (Fig. 2) and **1** · **2** · $\mathbf{7}_2$ (Fig. 4), respectively. Both crystal structures were solved and found to display an undulating pattern of hydrogen-bonding units of the 'crinkled tape' type as shown in Fig. 3 for the **1** · **7** assembly. The individual tapes are further associated by additional hydrogen bonds between a sidechain carbonyl of one strand and an indole NH of a neighboring one, leading to tapes related by a glide plane. There is a single such hydrogen bond per TAT unit, with the other indole NH not being involved in any hydrogen bond. The backbone of the ribbons is not completely planar but presents a ruffling that results from an $\approx 14°$ twist of the substituted amine nitrogen from the plane of the TAT ring. This nonplanarity resembles the propeller twist found between base pairs in DNA.

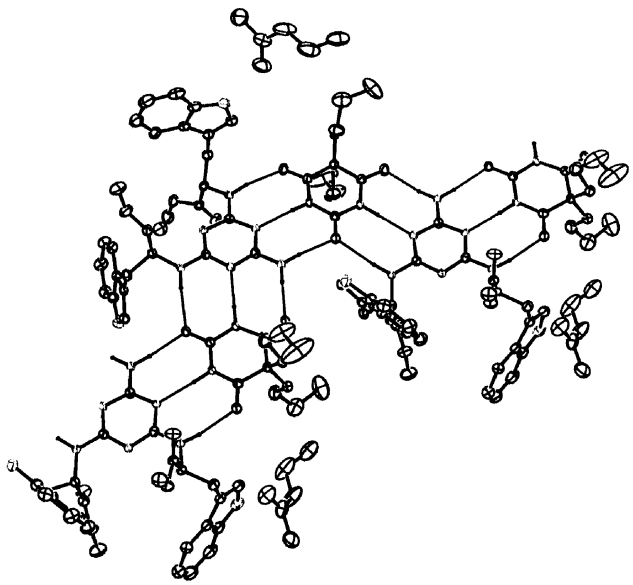


Fig. 4 ORTEP representation of the solid state structure of one homochiral strand of the racemic assembly **1** · **2** · $\mathbf{7}_2$. All hydrogen atoms not involved in hydrogen bonding are omitted for clarity. Ellipsoïds are scaled to enclose 30% of the electronic density. Hydrogen atoms have arbitrary radii

The centrosymmetric unit cell of the racemic **1** · **2** · $\mathbf{7}_2$ assembly (Fig. 4) contains two parallel crinkled tapes of composition **1** · **7** and **2** · **7**, each containing a single TAT enantiomer. Thus, during self-assembly and crystallization, chiral selection takes place within a given strand, whereby the triazine components are sorted into homochiral strands (Fig. 5). The relationship between adjacent tapes is different from that in the first structure, the hydrogen bonds relating the chains in the latter being replaced by solvent molecules (ethyl acetate). However, the same type of backbone ruffling is observed. Since each strand only carries a single enantiomer, one may describe it as supramolecularly isotactic in accordance with the terminology of polymer chemistry. This chiral selection process is related to the previously described formation of helical supramolecular structures from a racemic mixture of complementary components.[8]

The solid state structure of the *meso* assembly **3** · **7** would also be of much interest. Indeed, if one assumes a similar tape motif, the simplest ordered strands could present either centers of alternating chirality between adjacent units as read along the strand (···—(*R*,*S*)—(*R*,*S*)—(*R*,*S*)—(*R*,*S*)—···; isotactic) or centers of the same chirality between adjacent units (···—(*R*,*S*)—(*S*,*R*)—(*R*,*S*)—(*S*,*R*)—···; syndiotactic). Based on the structures presented here, it would seem that a syndiotactic structure could be expected for this **3** · **7** assembly. Unfortunately, cocrystals suitable for X-ray examination could not yet be obtained. Furthermore, it was in no case possible to produce suitable crystals from (**4**–**6**) · **7** associations.

Conclusion

The present results describe the self-assembly of a chiral TAT–barbiturate superstructure that sorts out enantiomers into different strands in the solid state. Such chiral selection, like that described previously,[8] also points to the possible role of supramolecular assemblies in the spontaneous generation of optical activity.[9]

Experimental

General

^{1}H and ^{13}C nuclear magnetic resonance (NMR) spectra were recorded on a Bruker SY 200 spectrometer at 200 MHz and 50.3 MHz, respectively, using the solvent as an internal refer-

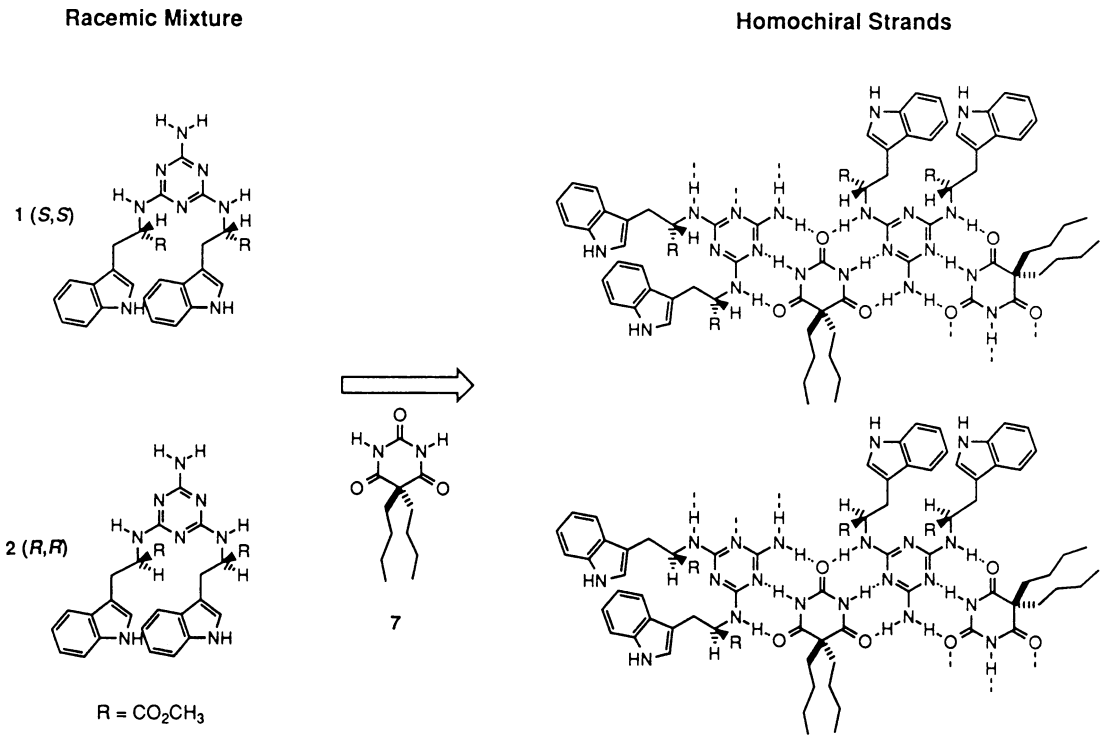


Fig. 5 Chiral selection in the self-assembly of a racemic mixture of **1** and **2** with **7**: formation of homochiral strands **1**·**7** and **2**·**7** in the crystals of the **1**·**2**·$\mathbf{7}_2$ assembly

ence. Infrared spectra (IR) were recorded on a Perkin-Elmer 1600 Series FTIR instrument. Melting points (mp) were recorded on an Electrothermal Digital Melting Point Apparatus and are uncorrected. Optical rotations were recorded on an Autopol III polarimeter. Ultraviolet and visible (UV/VIS) wavelength spectra were taken on a Cary-13 spectrometer. Luminescence spectra were recorded on a Shimadzu-R-450 spectrometer. Thin layer chromatography (TLC) was performed on Merck Kieselgel 60 F_{254} glass-backed plates (SiO_2). Purchased reagents were used without purification. Elemental analysis (%) were performed by the Service de Microanalyse, Institut de Chimie, Université Louis Pasteur, Strasbourg, or the Service Régional de Microanalyse, Université Pierre et Marie Curie, Paris, or the Service Central d'Analyse, Département Analyse Elémentaire, Centre National de la Recherche Scientifique, Lyon.

Syntheses

2-Amino-4,6-dichloro-1,3,5-triazine. This compound was prepared by a modification of the procedure of Diels.[6]

4*S*,6*S*-2-Amino-4,6-bis(1-carbomethoxy-2-indolylethylamino)-1,3,5-triazine, 1. Solid L-tryptophan methyl ester hydrochloride (1.27 g, 5 mmol) was neutralized with a saturated bicarbonate solution under reduced pressure (water aspirator). The aqueous solution was extracted with chloroform (4 × 30 mL) and the extracts dried over anhydrous sodium sulfate, filtered, and the filtrate concentrated by rotary evaporation under reduced pressure. The free amine was transferred to a 25 mL round-bottomed flask with 1,4-dioxane (6 mL). 2-Amino-4,6-dichloro-1,3,5-triazine (88.5 mg, 0.53 mmol) was added in one portion. The reaction was stirred and heated to reflux overnight. After cooling to room temperature, the solvents were removed by rotary evaporation under reduced pressure, and the residual oil was partitioned between ethyl acetate and 1 N hydrochloric acid (30 mL each). The organic layer was washed with additional 1 N hydrochloric acid (2 × 30 mL) and brine (30 mL) before drying over anhydrous sodium sulfate. The drying agent was filtered and the solvents removed by reduced pressure rotary evaporation. The solid was flash chromatographed on silica gel (43 g; 2.5 cm i.d. column) and the product eluted with ethyl acetate–methanol (98 : 2; v/v). After removal of the solvents and drying under high vacuum, 230 mg (81%) of the title compound **1** was isolated as a tan solid. mp 110–117 °C; ^{1}H NMR ($CDCl_3$) shows a mixture of three conformers: δ 8.01 (br s, 2H, indole), 7.55 (d, 2H, indole), 7.21 (d, 2H, indole), 7.09 (m, 4H, indole), 6.86 (br s, 2H, NH), 5.03 (br s, 2H, $ArNH_2$), 4.92 (dd, 2H, HC_α), 3.69 (s, 6H, CH_3; (m, 4H, H_2C_β); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 174.3, 165.7, 136.3, 127.4, 123.4, 121.9, 119.4, 118.3, 111.3, 109.8, 53.9 52.2, 27.7 (br); IR, cm^{-1} (thin film): 3476, 3424, 1741, 1601, 1530, 1441; FAB-MS: calcd 528.2233, found 529.3 $[M + 1]^+$; anal. calcd for $C_{27}H_{28}N_8O_4$: C, 61.35; H, 5.34; found C, 60.91; H, 5.38; $[\alpha]^{20}_D = +13.9°$ ($c = 0.48$, $CHCl_3$).

4*R*,6*R*-2-Amino-4,6-bis(1-carbomethoxy-2-indolylethylamino)-1,3,5-triazine, 2. This compound was prepared in an analogous manner to **1** in 65% yield. FAB-MS: calcd 528.2233, found 529.3 ($[M + 1]^+$, 100); anal. calcd for $C_{27}H_{28}N_8O_4$: C, 61.35; H, 5.34; found C, 60.98; H, 5.05; $[\alpha]^{20}_D = -13.9°$ ($c = 0.50$, $CHCl_3$).

4*R*-2-Amino-4-(1-carbomethoxy-2-indolylethylamino)-6-chloro-1,3,5-triazine. D-Tryptophan methyl ester hydrochloride (1.6 g, 6.2 mmol) was dissolved in a mixture of water (4 mL) and 1,4-dioxane (34 mL) in a 250 mL round-bottomed flask. Solid sodium bicarbonate (560 mg, 6.6 mmol) was added and the solution stirred for 30 min under reduced pressure (water aspirator). The resulting solution was diluted with additional 1,4-dioxane (50 mL) and 2-amino-4,6-dichloro-1,3,5-triazine (500 mg, 3.0 mmol) was added in one portion. The mixture was heated to reflux for 4 h. After cooling to room temperature the solvents were removed by rotary evaporation under reduced pressure. The residual oil was partitioned between ethyl acetate and 1 N hydrochloric acid (50 mL each). The organic layer was washed with additional 1 N hydrochloric acid (2 × 50 mL) and brine (50 mL) before drying over anhydrous sodium sulfate. The drying agent was filtered, washed with ethyl acetate, and silica gel (*ca.* 1 g) was added to the filtrate. The solvents were removed by rotary evaporation under reduced pressure and the solid flash chromatographed

on a silica gel column (50 g; 2.5 cm i.d. column), eluting with ethyl acetate–hexane (1 : 1; v/v). Fractions containing the product were combined, concentrated, and dried under high vacuum to afford 640 mg (61%) of the title compound as a tan solid. mp 76–78 °C; ^{1}H NMR shows a 1 : 1 mixture of rotamers ($CDCl_3$): δ 8.16 (br s, 1H, indole N–H), 8.02 (br s, 1H, indole N–H), 7.52 (br d, 1H, indole), 7.42 (br d, 1H, indole), 7.32 (br d, 1H, indole), 7.25 (br d, 1H, indole), 7.17 (br m, 6H, indole), 6.93 (br s, 1H, indole), 6.62 (br s, 1H, indole), 6.10 (br s, 1H, Ar–NH), 6.08 (br s, 1H, Ar–NH), 5.8 (v br s, 2H, $ArNH_2$), 5.5 (v br s, 2H, $ArNH_2$), 5.16 (m, 1H, HC_β), 4.96 (m, 1H, HC_α), 3.74 (s, 3H, CH_3), 3.68 (s, 3H, CH_3), 3.29 (m, 4H, $2H_2C_\beta$); ^{13}C NMR ($CDCl_3$): δ 173.3, 172.2, 169.5, 166.9, 165.7, 165.5, 136.2, 127.4, 123.0, 122.3, 119.7, 118.5, 111.3, 109.7, 54.0, 32.5, 28.0; IR, cm^{-1} (thin film): 3424, 3019, 1725, 1691, 1571, 1530, 1469, 1451, 1391; FAB-MS: calcd 346.0945, found 347.0 ([M + 1]$^+$, 100); anal. calcd for $C_{15}H_{15}ClN_6O_2$: C, 51.95; H, 4.36; found C, 52.32; H, 4.67; $[\alpha]^{20}_D = +11.9°$ (c = 1.03, $CHCl_3$).

4*R*,6*S*-2-Amino-4,6-bis(1-carbomethoxy-2-indolylethylamino)-1,3,5-triazine, 3. L-Tryptophan methyl ester hydrochloride (1.5 g, 6.0 mmol) was dissolved in water (100 mL) and neutralized with sodium bicarbonate (520 mg, 6.2 mmol) under reduced pressure (water aspirator). The aqueous solution was then continuously extracted with chloroform for 16 h. The organic extract was dried over anhydrous sodium sulfate, filtered, and concentrated by reduced pressure rotary evaporation. The viscous oil was transferred to a 25 mL round-bottomed flask with chloroform (*ca.* 3 mL). 4*R*-6-Amino-4-(1-carbomethoxy-2-indolylethylamino)-2-chloro-1,3,5-triazine (620 mg, 1.8 mmol) was dissolved in chloroform (*ca.* 5 mL) and added to the L-tryptophan solution. The solvents were removed by rotary evaporation under reduced pressure and the residue heated at 100 °C for 10 min, leaving a tan solid. 1,4-Dioxane (4 mL) was added and the slurry was heated to reflux for 2 h. After cooling and removal by rotary evaporation of the solvent, the resulting solid was partitioned between ethyl acetate and 1 N hydrochloric acid (30 mL each). The organic layer was separated and washed with additional 1 N hydrochloric acid (2 × 30 mL) and brine (30 mL) before drying over anhydrous sodium sulfate. The drying agent was filtered, washed with ethyl acetate, and the filtrate concentrated by rotary evaporation under reduced pressure. The crude product was flash chromatographed on silica gel (50 g; 2.5 cm i.d. column) and the product eluted with ethyl acetate–methanol (98 : 2; v/v). The combined fractions containing the product were concentrated under reduced pressure and dried under high vacuum to yield 720 mg (76%) of the title compound, **3**, as a tan solid. mp 142–146 °C; ^{1}H NMR ($CDCl_3$): δ 7.96 (br s, 2H, indole), 7.54 (br d, 2H, indole), 7.22 (br m, 6H, indole), 6.86 (br d, 2H, indole), 5.90 (br s, 2H, Ar–NH), 4.93 (br d, 2H, $ArNH_2$), 3.65 (br s, 6H, CH_3), (br d, 4H, H_2C_β); ^{13}C{^{1}H} NMR shows a mixture of rotamers ($CDCl_3$): δ 174.3, 165.7, 136.3, 127.4, 123.4, 121.9, 119.4, 118.3, 111.3, 109.8, 53.9 52.2, 27.7 (br); IR, cm^{-1} (thin film): 3476, 3426, 1735, 1572, 1512, 1440; FAB-MS calcd 528.2233, found 529.2 ([M + 1]$^+$, 100); anal. calcd for $C_{27}H_{28}N_8O_4$: C, 61.35; H, 5.34; found C, 60.51; H, 5.25.

4*R*,6*R*-2-Amino-4,6-bis(1-phenylethylamino)-1,3,5-triazine, 4. This material was prepared in an analogous manner to **1** starting from *R*-(+)-α-methylbenzylamine. Yield 72%. mp 75.4–77.2 °C; ^{1}H NMR ($CDCl_3$) δ 7.3 (m, 10H, aromatic), 5.19 (br s, 2H, 2 N–H), 5.09 (br s, 2H, 2 C–H), 4.73 (br s, 2H, 2 NH_2), 1.43 (br s, 6H, 2 CH_3); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 166.9, 165.6, 144.5, 128.5, 126.9, 49.7 (br), 22.6; IR, cm^{-1} (thin film): 3407, 3264, 3026, 1568, 1502, 1444; EI-MS: calcd 334.1906, found 334.3 ([M + 1]$^+$, 63), 120.2 (100); anal. calcd for $C_{19}H_{22}N_6$: C, 68.24; H, 6.63; N, 25.13; found C, 68.09; H, 6.55; N, 25.34; $[\alpha]^{20}_D = +142°$ (c = 0.50, $CHCl_3$).

4*S*,6*S*-2-Amino-4,6-bis(1-phenylethylamino)-1,3,5-triazine, 5. This compound was prepared in an analogous manner to **4** from (*S*)-(−)-α-methylbenzylamine in 67% yield. Anal. calcd for $C_{19}H_{22}N_6$: C, 68.24; H, 6.63; N, 25.13; found C, 67.99; H, 6.69; N, 24.93; $[\alpha]^{20}_D = -144°$ (c = 0.50, $CHCl_3$).

4*S*-2-Amino-6-chloro-4-(1-phenylethylamino)-1,3,5-triazine. Aminodichlorotriazine (750 mg, 4.54 mmol) was suspended in acetone (25 mL). *S*-(−)-α-Methylbenzylamine (0.65 mL; 5.04 mmol) and solid sodium bicarbonate (450 mg, 5.35 mmol) were added. The reaction was stirred and heated to reflux for 10 h. The reaction was evaporated to dryness and worked up as described in the synthesis of 4*R*-2-amino-4-(1-carbomethoxy-2-indolylethylamino)-6-chloro-1,3,5-triazine. Yield 97%. mp 166.2–167.0 °C; ^{1}H NMR ($CDCl_3$): δ 7.3 (m, 10H, aromatic), 5.96 (v br s, 4H, 2 Ar–NH_2), 5.80 (d br s, 1H, Ar–NH), 5.56 (d br s, 1H, Ar–NH), 5.25 (m, 1H, HC_α), 5.11 (m, 1H, HC_α), 1.50 (d, 6H, 2 CH_3); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 167.2, 165.3, 143.0, 128.7, 127.4, 125.9, 50.5, 22.3; IR, cm^{-1} (thin film): 3410, 3266, 1554, 1500; FAB-MS calcd 249.0781, found 250.1 ([M + 1]$^+$; 100); anal. calcd for $C_{11}H_{12}ClN_5$: C, 52.91; H, 4.84; N, 28.05; $[\alpha]^{20}_D = +133°$ (c = 0.97, $CHCl_3$).

4*R*,6*S*-2-Amino-4,6-bis(1-phenylethylamino)-1,3,5-triazine, 6. This material was synthesized in an analogous manner to **3**, from 4*S*-2-amino-6-chloro-4-(1-phenylethylamino)-1,3,5-triazine and (*R*)-(+)-α-methylbenzylamine. Yield 76%. mp contracts 90 °C, melts 142–144 °C; ^{1}H NMR ($CDCl_3$): δ 7.25 (m, 10H, aromatic), 5.12 (m, 4H, NH_2 and 2C–H), 4.63 (br s, 2H, 2NH), 1.50 (d, 6H, $2CH_3$); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 164.6, 144.3, 128.4, 126.9, 125.9, 49.8, 22.5; IR, cm^{-1} (thin film): 3410, 3261, 3021, 1572, 1508, 1443; EI-MS: calcd 334.1906; found 335.2 ([M + 1]$^+$, 63), 120.2 (100); anal. calcd for $C_{19}H_{22}N_6$: C, 68.24; H, 6.63; N, 25.13; found C, 68.52 ; H, 6.83; N, 24.84.

X-Ray structure analyses

1·7: $C_{39}H_{48}N_{10}O_7$, MW = 768.9, colorless crystals, orthorhombic, a = 17.158(5), b = 15.624(4), c = 14.742(4) Å, V = 3952.0 Å^3, Z = 4, ρ_{calc} = 1.292, λ = 1.5418 Å, μ = 7.111 cm^{-1}, space group $P2_12_12_1$.

1·2·7$_2$·$C_4H_8O_2$ (ethyl acetate): $C_{43}H_{56}N_{10}O_9$, MW = 857.0, colorless crystals, monoclinic, a = 9.877(5), b = 16.401(7), c = 28.911(9) Å, b = 96.79(2)°, V = 4650.5 Å^3, Z = 4, ρ_{calc} = 1.224, λ = 1.5418 Å, μ = 6.841 cm^{-1}, space group $P2_1/c$.

Suitable single crystals of **1·7** and **1·2·7$_2$** (0.20 × 0.20 × 0.20 and 0.40 × 0.20 × 0.20 mm^3 respectively) were obtained by slow diffusion of pentane or hexane into a concentrated solution of the complexes in ethyl acetate, and mounted at the end of a glass fiber. Reflections (2528 for **1·7** and 5128 for **1·2·7$_2$**) were collected on a Philips PW1100/16 instrument at −100 °C with Cu graphite monochromated radiation, θ/2θ flying step scans, step width = 0.04°, scan speed = 0.020 (**1·7**) and 0.024 deg s^{-1} (**1·2·7$_2$**), scan width = 0.80 (**1·7**) and 0.90 (**1·2·7$_2$**) + 0.14 tg(θ)°, 3° < θ < 52° (**1·7**), 50° (**1·2·7$_2$**). Three standard reflections measured every hour during the data collection periods showed no significant trend. The raw data were converted to intensities and corrected for Lorentz and polarization factors. The structures were solved using direct methods. The reflections with $I > 3\,\sigma(I)$ (2135 for **1·7** and 2908 for **1·2·7$_2$**) were used to determine and refine the structures. Hydrogen atoms were introduced as fixed contributors by their computed coordinates (X—H = 0.95 Å) and isotropic temperature factors such as $B_H = 1.3\,B_{eqv}(X)$ Å^2. No absorption corrections were

applied. The absolute structure of **1**·**7** was determined by comparing x, y, z and $-x$, $-y$, $-z$ refinements and confirmed by refining Flack's x [0.14(20)]. Molen (Molen, an Interactive Structure Solution Procedure, Enraf-Nonius, Delft, The Netherlands, 1990) on a DEC Alpha 3600 computer was used for all calculations. Final $R(F) = 0.041$ and 0.045 for **1**·**7** and **1**·**2**·$\mathbf{7}_2$, respectively.
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